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ESTIMATING COOLING LOADS FOR AIR-CONDITIONING SWINE HOUSING

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INTRODUCTION

Recent studies (1) provide the sensible and latent heat loads for designing mechanical air-conditioning systems for hog houses. These and other studies (2, 3), conducted cooperatively by the U. S. Department of Agriculture and the California Agricultural Experiment Station at Davis, suggested the desirability of providing optimum ambient air conditions for swine. Heitman, Kelly, and Bond (2) have shown that 100-pound hogs, under controlled constant temperature, gain most rapidly when the ambient air is 73°F, while the optimum air temperature for 200-pound hogs is about 68°F. Air conditioning, then, should be an effective means of increasing hog production during the summer in most hog-producing areas. It should also serve as a means of extending hog production into areas now unsuitable because of extreme summer conditions. Other benefits attributed to air conditioning include reduction of the fly problem within the enclosed conditioned space; increased comfort of sows (producers who have installed conditioning equipment claim as high as 2 extra pigs saved per litter (4) because the sow moves less to find coolness); and better nursing of pigs (also because of decreased restlessness of the sow).

In considering air conditioning, hog producers must first consider the investment involved. Blanket recommendation of air conditioning is not possible; each producer must weigh possible benefits against the cost of equipment and operation. To help determine the investment that might be required to air-condition hog houses, an analysis is presented of a method of estimating cooling loads for various permanent houses that might be used in major hog-producing areas of the United States.

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DESIGN CONDITIONS

Before calculating cooling loads in hog houses, the outside and inside design temperature conditions must be determined. As an aid in selecting outside design temperature conditions, figure 1 shows the division of major hog-producing areas of the United States into five regions on a basis of similar wet- and dry-bulb design temperatures. It is intended that these regions be used as a general guide, rather than design conditions for a specific locality. Local conditions, if known, should be used to increase the accuracy of the cooling-load estimate. Reference 5 gives design conditions for many localities of the country.

Inside design conditions will vary with the type and weight of animals to be housed. In some cases, the producer may feel justified in permitting a higher inside condition than optimum, to reduce costs. Suggested temperatures are shown on the cooling-estimate form ("NOTES", figure 5).

The suggested air temperatures for fattening pigs are based on weight-gain trials in a controlled-temperature room (2). Similar data are not available for gestating sows or sows with litters, and the suggested temperatures for these groups are based on observations of their reactions to various air temperatures in the controlled-temperature room. A temperature of 75°F is suggested for the latter group as a compromise between observed comfortable temperatures for the sow and for the litter.

CALCULATION OF COOLING LOADS

Sources of heat constituting cooling loads are:

1) Heat transmission through walls, roof, etc., due to indoor-outdoor temperature difference and solar energy (sensible heat)

2) Heat and moisture released by hogs (sensible and latent heat)

3) Infiltrating or ventilating air (sensible and latent heat)

4) Heat from lights and equipment (sensible heat)

The components are illustrated in figure 2.

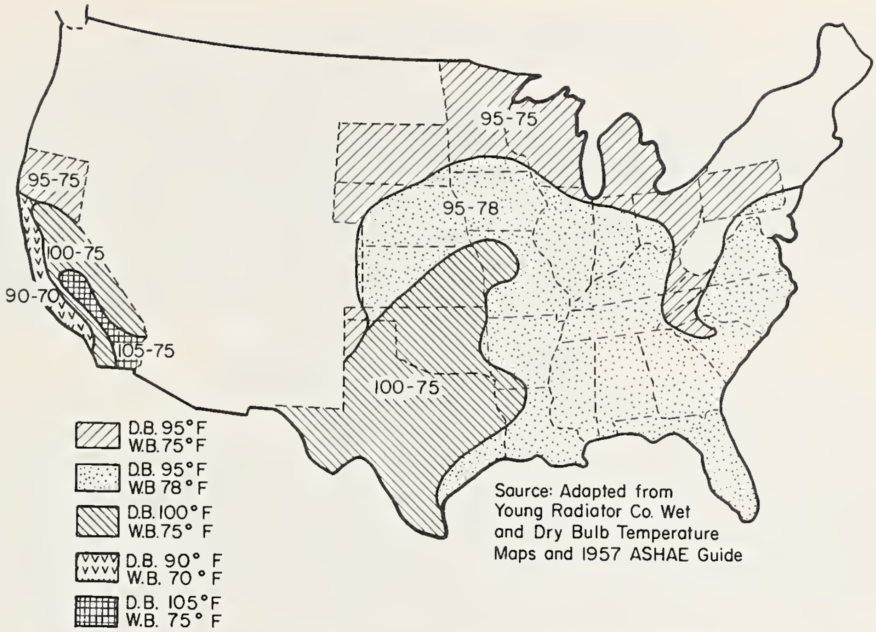
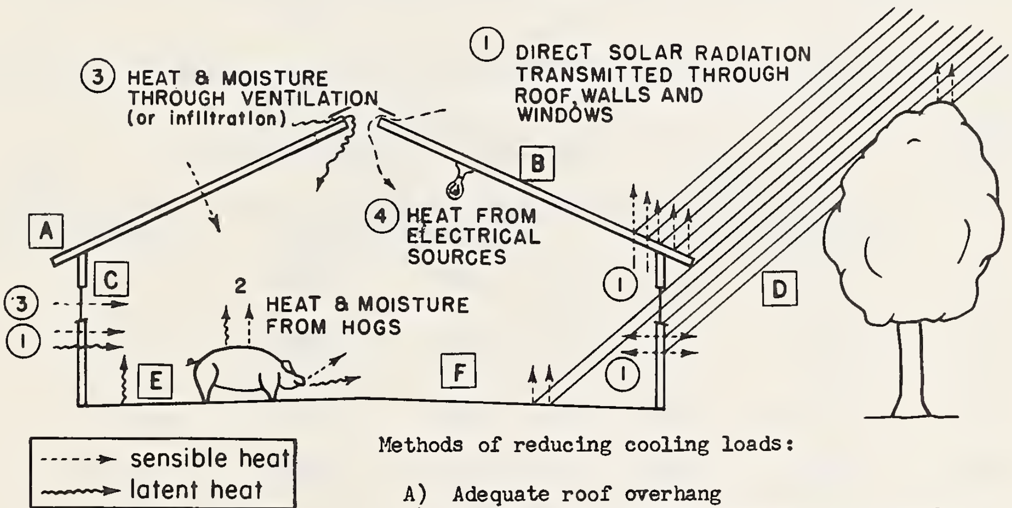


Figure 1. Summer temperature zones for major hog producing areas of the United States (for duration of high temperatures, see figs. 6 and 7).



Methods of reducing cooling loads:

A) Adequate roof overhang
B) Construction and color of walls and roof
C) Window location and shading by awnings
D) Shading by trees or artificial means
E) Sloped floors to drain excess water
F) Remove unnecessary heat or moisture producing equipment

Figure 2. Sources of heat gains in hog houses, with possible methods of reduction.

Heat Gains Through Walls and Roof

Heat gains due to the indoor-outdoor air temperature difference and solar energy may be determined from figures 3 and 4. These charts are based on heat-transmission data for various types of construction (5) and accepted practices for determining solar heat gains (6). Four typical constructions are indicated for the walls, roof, and doors, so that the charts will apply to most present or planned permanent hog housing. Use of the charts is illustrated later in an example.

Heat Gains From Animals

Previously mentioned studies conducted in a constant-temperature chamber provided data for determining heat gains from animals. Animal heat and moisture that contribute to the cooling load can be determined from table 1, 2, or 3. These values should be considered as sensible and latent heats contributed by the animals to the room. Their sum is the total heat lost by the hogs. The ratio of sensible to latent heat from the hogs may, however, be quite different than the ratio for the conditioned space, due to utilization of some animal sensible heat in vaporizing moisture on the floor. Use of the values assumes that conditions and management practices in the area to be air-conditioned will be similar to those of the test chamber (well-drained floors, no bedding, floor cleaned twice daily); this is normally quite valid (1).

Table 1. Room heat gains contributed by fattening pigs*, Btu/hr/pig.

Weight (lbs.)	Room Temperature					
	70°F		75°F		80°F	
	Sensible	Latent	Sensible	Latent	Sensible	Latent
50	155	188	126	209	93	246
100	221	219	178	252	141	286
150	270	255	225	288	181	321
200	324	279	273	315	223	348
250	376	298	320	330	270	366
300	436	308	376	339	327	370
350	504	307	440	338	392	364
400	581	295	522	317	468	345

* These data may also be used as estimates for open sows or boars.

Table 2. Room heat gains contributed by gestating sows at constant temperatures, Btu/hr/sow

	Room Temperature	
	70°F	80°F
Sensible Heat	624	324
Latent Heat	812	915

Table 3. Room heat gains from a pen containing a unit of one sow and litter at 75°F, Btu/hr per unit. These data represent averages of two tests - one an 80°F environment with a Poland China sow and the other a 70°F environment with a Berkshire sow (1).

Number of Weeks After Farrowing	Sensible Heat	Latent Heat	Total Average Weight of Sow and Litter, lbs.
1	840	960	360
2	930	1010	375
3	1020	1060	390
4	1115	1110	405
5	1210	1170	425
6	1310	1210	445
7	1410	1260	465
8	1510	1305	485

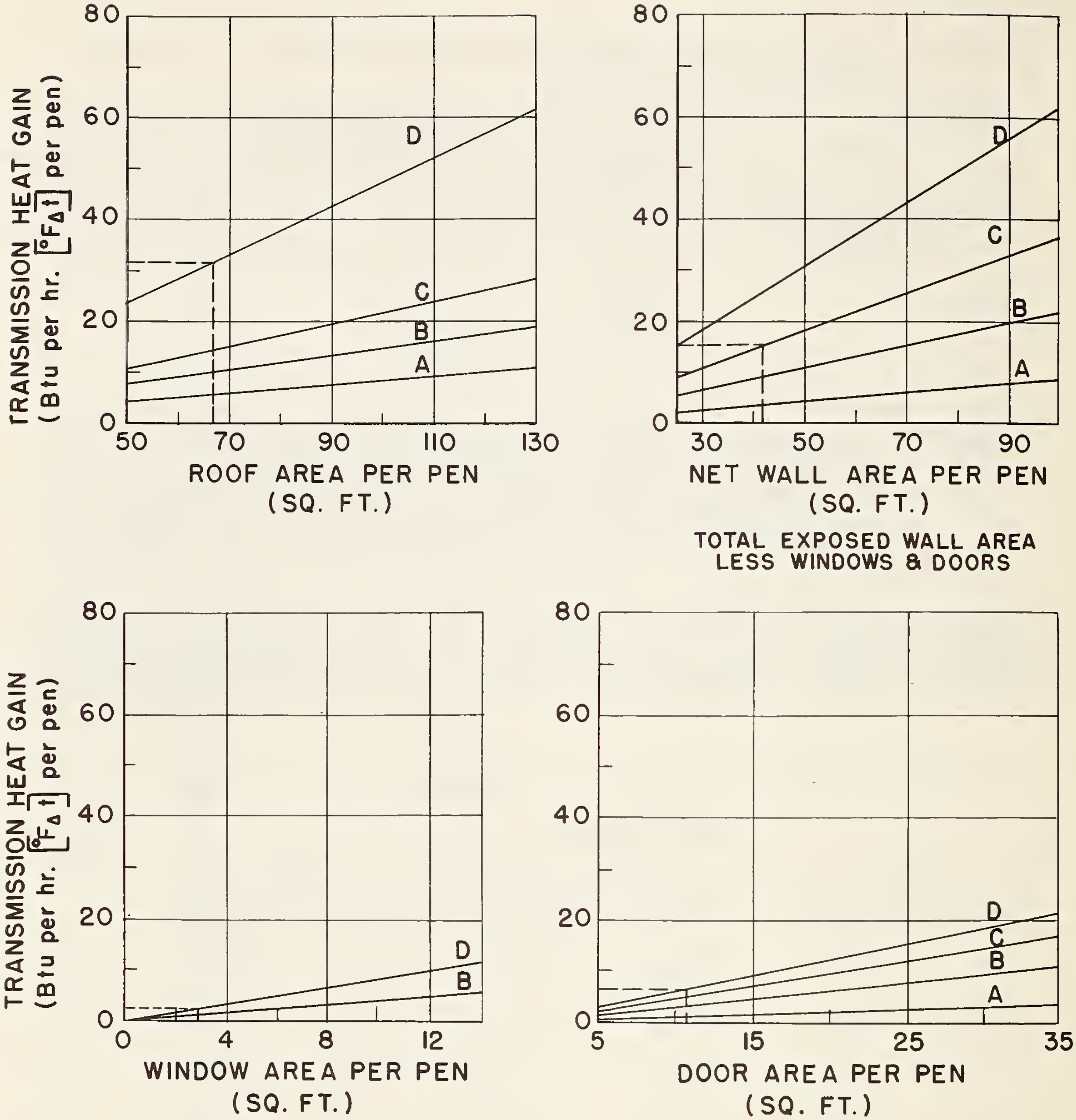


Figure 3. Heat transmission gains from indoor-outdoor temperature differences for hog houses of various construction.

TYPICAL CONSTRUCTIONS DENOTED BY CLASSIFICATIONS 1/:

Construction Type "A":
Walls: 3/8" plywood, 1/2" insulation board sheathing, 2" blanket insulation in stud space, with 1/4" plywood or hardboard inside (U = 0.090)
Roof 2/: Roll roofing, 1/2" plywood decking, 2" blanket insulation, with 3/4" insulation board on underside (U = 0.085)
Doors: 3/8" plywood both sides of 2" frame members with 2" blanket insulation between (U = 0.110)

Construction Type "B":
Walls: 8" cinder block, core filled with rock wool; or 3/4" drop siding and building paper outside with 1/2" insulation board covered with 3/8" plywood inside (U = 0.225)
Roof 3/: Roll roofing on 3/4" solid lumber decking with 1" insulating board on underside of rafters (U = 0.150)
Windows: Double glass panes separated by 1/4" air space (U = 0.625)
Doors: 1/2" plywood both sides of 2" frame members, no insulation (U = 0.325)

Construction Type "C":
Walls: 8" cinder block or hollow clay tile; or 3/8" plywood both sides of studs; or 3/4" drop siding, building paper, and 3/4" plywood sheathing (U = 0.370)
Roof: Roll roofing on 3/4" solid lumber decking with 1/2" insulation board on underside of rafters (U = 0.220)
Doors: 1-1/2" matched lumber (U = 0.500)

Construction Type "D":
Walls: 8" poured concrete or 3/4" drop siding on studs, no insulation or interior wall lining (U = 0.625)
Roof: Roll roofing on 3/4" solid lumber decking, no insulation or interior wall lining (U = 0.475)
Windows: Single pane glass (U = 1.110)
Doors: 3/4" matched lumber (U = 0.625)

1/ Insulated surfaces should have vapor barriers adjacent to the inside wall lining. Floors should be constructed on well-drained sites, and should be insulated. (See reference 9)

2/ An equivalent roof and ceiling combination (attic space ventilated) would be roll roofing on wood decking with a ceiling of 3" blanket insulation with 1/4" plywood or hardboard on underside.

3/ An equivalent roof and ceiling combination would be same as 2/ above, with 1" blanket insulation instead of 3".

Figure 3. Description of hypothetical construction used for calculation of data shown on previous page.

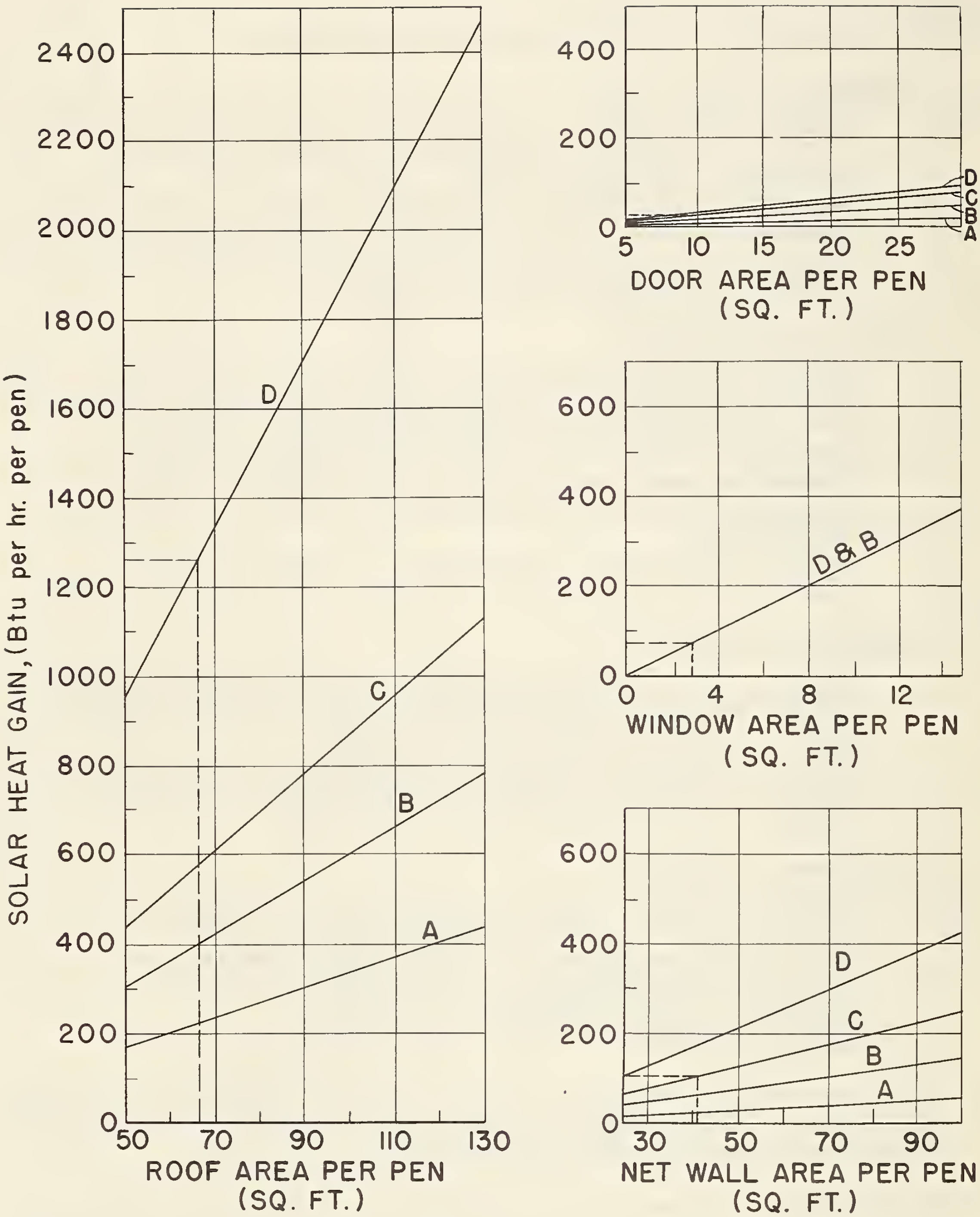


Figure 4. Solar heat gains for hog houses. Normally usable without latitude correction. (See figure 3 for typical constructions corresponding to classifications.)

Heat Gains From Ventilation and Infiltration

To reduce the concentration of ammonia and odors produced, a means of ventilation is required. The ventilation rates indicated in the estimate form, figure 5, should be sufficient. To reduce the cooling load, it may be desirable to reduce the ventilation rate during the hottest portion of the day; then, during the night ventilation will be increased to eliminate any odor and ammonia build-up that has occurred. In practice, outside air is assumed to infiltrate when the ventilation rate is less than one air change per hour (6). When this occurs, infiltration must be considered as an additional cooling load, as noted on the estimate form.

Heat Gains From Lights and Equipment

Ordinarily, in hog housing, there would be no other major sources of heat except fan motors and lights. However, it is possible that motors on equipment, such as feed grinders, may be operating within the conditioned area during the hot periods of the day; if so, heat gains from these sources should be included in the estimates (1 hp. = 3180 Btu/hr for estimating purposes).

A COOLING ESTIMATE FORM

A cooling estimate form is suggested to facilitate calculations of the cooling load of an air-conditioned space. Figure 5 shows sample calculations for a 12-pen farrowing house, housing 12 sows with litters. Information similar to the following (obtained from the building plans or by measurement) is required: Total roof area, 804 sq. ft.; net wall area (total wall less doors and windows), 502 sq. ft.; total floor area (including alleyway), 720 sq. ft.; total window area, 36 sq. ft.; total door area, 128 sq. ft.; volume, 5400 cu. ft. The structure is uninsulated, with 8" cinder-block walls, roll roofing on a matched-lumber deck, doors constructed of 1" x 8" boards, and single-thickness glass windows. Assumed location is central Iowa.

The procedure for estimating hog house air-conditioning requirements follows:

<u>Step 1.</u> For each structural component (roof, wall, etc.), determine the area per pen and enter as Item 1 of the estimate form.

<u>Step 2.</u> Enter under Item 2 the outside design conditions from figure 1 (or local design conditions, if known), and the inside design conditions from Items 8a and b of the estimate form. Humidity ratio values may be estimated from data given in Item 8c, or from a psychrometric table. Values of Δt and ΔM are obtained by appropriate subtractions.

<u>Step 3.</u> Determine from figure 3 the transmission heat gains (item 3a) as follows:

STRUCTURE: TYPE AND LOCATION 12 Pen Farrowing House, Ames Iowa DATE 1/15/59 ESTIMATED BY GLH

DIMENSIONS OF CONDITIONED SPACE 20'x36'x 7½' avc. roof height OCCUPANTS Sows & Litters NUMBER 12 WT. —

1. STRUCTURAL COMPONENTS:

a. Roof area per pen	67.0	Sq. Ft.
b. Net wall area per pen	41.8	
c. Floor area per pen	60.0	
d. Window area per pen	3.0	
e. Door area per pen	10.7	

2. DESIGN CONDITIONS:

	Dry Bulb	Wet Bulb	Rel. Humidity	Humidity Ratio
a. Outside	95 °F	78 °F	— %	117.5 gr./lb.
b. Inside	75	—	50	65.9
c. Difference	20 = Δt			51.6 = ΔM

3. SENSIBLE HEAT GAIN - PER PEN BASIS:

a. Transmission heat gain, per pen	1120	Btu/hr.
b. Solar heat gain, per pen	1477	
c. Animals (1 units/pen x 1510 Btu/hr/unit)	1510	
d. Infiltration (0 cfm/pen x ___ Δt x 1.08)	0	
e. Lights and equipment (0 watts x 3.4)	0	
f. Unit fan motors (5% of pen sensible heat)	205	
g. Other none	0	
PEN SENSIBLE HEAT		4312 Btu/hr.

4. LATENT HEAT GAIN - PER PEN BASIS:

a. Animals (1 units/pen x 1305 Btu/hr/unit)	1305	
b. Infiltration (0 cfm/pen x ___ ΔM x 0.68)	0	
c. Other none	0	
PEN LATENT HEAT		1305 Btu/hr.

5. VENTILATION AIR HEAT GAIN - PER PEN BASIS:

a. Sensible (20 cfm/pen x 20 Δt x 1.08)	432	
b. Latent (20 cfm/pen x 51.6 ΔM x 0.68)	702	
VENTILATION HEAT GAIN		1134 Btu/hr.

6. TOTAL HEAT GAIN PER PEN:

Sum of Sensible, Latent, and Ventilation 6751 Btu/hr.

7. GRAND TOTAL HEAT (GTH) FOR ENTIRE CONDITIONED SPACE:

a. TOTAL GAIN PER PEN (6751) x 12 PENS 81,012 Btu/hr.
b. MINIMUM TONS OF AIR CONDITIONING REQUIRED (GTH/12000) 6.75 Tons

8. NOTES:

a. Inside design temperatures and suggested fresh air ventilation rates for hogs:

Animal Unit	Inside Design Temperature, °F	Ventil. Rates (cfm/animal unit)
Sows and litters	75	20
Gestating sows	70	10
Fattening pigs (100-200 lbs.)	70	10

b. Inside design relative humidity near 50%.

c. Grains water per lb. dry air - selected conditions

Dry Bulb	Wet Bulb	Rel. Humidity	Humidity Ratio
95°	78°		117.5 grains/lb.
95°	75°		98.8
100°	75°		90.6
75°		50%	65.9
70°		50%	55.6

d. To check for infiltration:
Infiltration = 1 air change/pen/hr.
If greater than total ventilation rate per pen for occupants, enter answer after "INFILTRATION" on form. If less, enter "0" for "INFILTRATION".

e. Capacity of air conditioning unit circulating fan may be accurately estimated in most cases by

$$CFM = \frac{\text{Pen Sensible Heat x Number Pens}}{20} = 2590$$

Figure 5. Cooling estimate form for use in determining hog house air conditioning loads. For explanation of example, see text.

a. Enter each of the graphs with the area per pen of the respective structural components.

b. Proceed vertically to the line most nearly representing the type of construction involved. Component heat transmission classifications of the example are: Roof, "D"; walls, "C"; windows, "D"; and doors, "D".

c. Read the heat gain per pen (Btu/hr per °F Δt) for each component. For the example, gains per pen are: Roof, 31.6 Btu/hr per °F Δt; net wall, 15.2; window, 2.3; door, 6.9.

d. Add the gains. Gains per pen for the example are 56.0 Btu/hr per °F Δt.

e. Multiply this sum of heat gains by Δt (from Item 2) to obtain transmission heat gain per pen (Item 3a). Total gain for the example equals 56.0 x 20, or 1120 Btu/hr per pen.

Step 4. To obtain solar heat gain per pen (Item 3b), repeat parts a, b, c, and d of Step 3, using figure 4. The sum obtained from the graphs for the structural components is the total solar gain (Btu/hr per pen) to enter under Item 3b. Summing solar heat gains per pen for the example gives 1265 Btu/hr roof gain + 105 wall gain + 74 window gain + 33 door gain, for a total of 1477 Btu/hr per pen.

Step 5. Obtain sensible and latent heat gains for the animals from tables 1 (fattening pigs), 2 (gestating sows), or 3 (sows with litters). Enter these gains on the estimate form under Items 3c and 4a. For the sows with litters (one unit per pen) in the example, assuming they will remain in the house eight weeks, figure 5 shows a sensible heat of 1510 Btu/hr per unit and a latent heat of 1305 Btu/hr per unit, the maximum in Table 3.

Step 6. Suggested ventilation air rates are given under Item 8a of the estimate form. The suggested rate for sows with litters is 20 cfm/unit. Either this value or that of infiltration (whichever is greater) should be used. Infiltration is checked as follows: One air change per hour in the house under consideration is equivalent to 5400 cu. ft. per hr/(60 x 12 pens), or 7.5 cfm per sow and litter. Since this is much less than suggested, the value of 20 cfm is entered on the estimate form (Items 5a and b for ventilating air; Items 3d and 4b for infiltrating air). Perform indicated operations.

Step 7. Heat gains from lights and equipment other than the conditioning unit fan motors are entered under Item 3f on the form. In the example, window area was sufficient for adequate daytime lighting and heat lamps were not used, so "0" is entered.

Step 8. Five percent of the pen sensible heat (Items 3a, b, c, d, e, and g) is now added as Item 3f to account for heat from the unit fan motors (6). This amount is .05 x 4107, or 205 Btu/hr per pen for the example.

Step 9. All heat gains are totaled to obtained the over-all cooling load per pen (Item 6). Total for the example is 6751 Btu/hr per pen.

Step 10. Total load for the conditioned space (Item 7a) is obtained by multiplying the results of Step 9 by the number of pens. To convert to tons of refrigeration required (Item 7b), divide Item 7a by 12000. (One ton of refrigeration is defined as the absorption of heat at the rate of 12000 Btu/hr.) For the example, total load for the building is 6751 x 12, or 81,012 Btu/hr. The minimum tons of refrigeration required equals 81,012 divided by 1 2,000, or 6.75.

Should this value appear high, the possibility of partially insulating the building might be considered. This would change only the values obtained in Steps 3 and 4. Using the same walls, windows, and doors, but adding insulation to the roof of the example so it matches type "A" construction, the transmission heat gains per pen become 30.0 Btu/hr per $°F\Delta t$ x $20°F\Delta t$, or 600 Btu/hr per pen (the new roof transmission gain per pen equals 5.6 Btu/hr per $°F\Delta t$). The solar roof gain becomes 223 Btu/hr per pen, for a total solar heat gain of 435 Btu/hr per pen. Thus, by improving the roof construction, the total transmission and solar heat gains per pen are reduced to 1035 Btu/hr. The over-all cooling load per pen is lowered to 5200 Btu/hr, or a total of 5.2 tons for the entire conditioned space.

As a guide to serve as a rough check on calculations for constructions similar to the "B" classification, table 4 gives the cooling required per pen for an "average" house for three major design regions of figure 1. This "average" house, based on ten permanent-type swine housing plans (7) offered by the Midwest Plan Service, has the following structural component areas per pen: Roof, 93.0 sq. ft.; walls (net), 60.5 sq. ft.; windows, 5.6 sq. ft.; floor (including alleyway), 88.7 sq. ft.

Table 4. Cooling loads per pen as calculated for "average" house (see text) with various ventilation rates, occupants, and design regions. These are guide values; only to be used in checking loads estimated from the cooling estimate form.

Outside Design Conditions		Ventilation Rate Per Pen		
D.B. (°F)	W.B. (°F)	15 cfm*	20 cfm**	80 cfm**
Occupants:	1 Sow and litter per pen (Inside conditions: 75°F, 50% R.H.)			
100	75	5250 Btu/hr	5475 Btu/hr	--
95	78	5275	5575	--
95	75	5075	5325	--
Occupants:	2 Gestating sows per pen (Inside condition: 70°F, 50% R.H.)			
100	75	5450 Btu/hr	5750 Btu/hr	--
95	78	5475	5850	--
95	75	5175	5450	--
Occupants:	8 Fattening pigs per pen (Inside conditions: 70°F, 50% R.H.)			
100	75	6850 Btu/hr	--	10600 Btu/hr
95	78	6875	--	11450
95	75	6700	--	10450

* Minimum obtainable with this "average" due to infiltration.

** Recommended values for number of occupants shown.

METHODS OF REDUCING COOLING LOADS

As noted in the example above, insulation is one of the most effective methods of reducing the sensible-heat cooling loads. However, insulation is costly, and a point (varying with the locality, and the cost of refrigeration equipment and insulation) is soon reached where the addition of more insulation becomes uneconomical. Then other methods should be considered, as suggested in figure 2 and discussed below:

1. Painting roof covering and walls white or light-colored to reduce solar radiation gain (sensible heat). This allows a reduction in the values obtained from figure 4 by one-fourth to one-half, providing the surfaces can and will be maintained in good reflective condition (6).

2. Shading windows and walls exposed to the sun with trees, louvered shades, roof overhangs, or exterior shades to reduce solar radiation (sensible heat).

3. Placing the feed and storage room at the end of the house most exposed to the effect of the sun to reduce solar radiation (sensible heat).

4. Removing urine and other excess water by using sloped and well-drained floors to reduce evaporation within the building (latent heat).

5. Using a variable-rate ventilation system to reduce the extreme effects of admitting outside air (sensible and latent heat). Such a system would reduce the amount of fresh air admitted when outdoor air temperatures rise, and increase it when outdoor temperatures fall. Automatic control for varying the fresh air could be accomplished by an outdoor temperature-sensing thermostat controlling a damper motor of the modulating type. The cost would be much less than the cost of providing additional cooling necessary to admit the suggested ventilation rates at all times.

6. Removing power equipment from the conditioned space, where possible, to reduce the heat gain from motors (sensible heat). This would particularly apply to equipment, such as feed grinders, that might run for relatively long periods during the hot portions of the day.

OPERATING COSTS

After determining cooling capacity requirements, the cost of operating the required equipment must be considered before any purchases are made. The major costs are annual maintenance, depreciation of equipment, and power consumption. The first two are usually estimated as a percentage of initial installed cost. Power consumption, however, is rather difficult to estimate; factors include operating time of the equipment, motor size (power input), and cost of electricity per kilowatt-hour. Power input and electrical rate can be readily determined for a given unit and a specific locality, but operating time depends on many variables, such as 1) ratio of equipment capacity to the actual in-use cooling load of the hog house, 2) heat-storage characteristics of the building and materials stored within it (such as feed), 3) ventilation system used, 4) swine heat and moisture production (changes as animals increase in size during the summer cooling period), and 5) utilization of cool night air when conditions are lower outside than inside.

A basis for estimating operating time for cooling equipment, showing the number of hours conditions are normally above those at which air conditioning would begin for fattening pigs or gestating sows, is given in figure 6; figure 7 shows the same for sows with litters. The maps cover the period June through September, inclusive, and are based on outside dry- and wet-bulb temperatures (8). The hours of actual operating time may be greater or less than indicated on the maps, because of the influence of the five factors noted above.

OTHER CONSIDERATIONS

Some air from the conditioned space must be recirculated (as with human housing) to keep air-conditioning costs within reason. This recirculated air contains great quantities of dust picked up from feed, bedding, and other sources. If unfiltered, the dust-laden air tends to clog the cooling coil, causing a drop in cooling capacity. The obvious answer is to filter the recirculated air; with present filters, this requires frequent cleaning or an expensive self-cleaning filter system.

Because of the high occupant density and ventilation loads in hog housing and the high proportion of the latent heat, packaged air-conditioning units designed for human housing may not be suitable for conditioning hog houses. To be sure of obtaining the ratio of latent and sensible cooling to maintain desired conditions, as well as the required cooling capacity, a qualified engineer should design the air conditioning system for the particular situation. The supplier should guarantee the system to perform as designed for one full operating season. Equipment should be guaranteed against mechanical failure for one year from date of final acceptance.

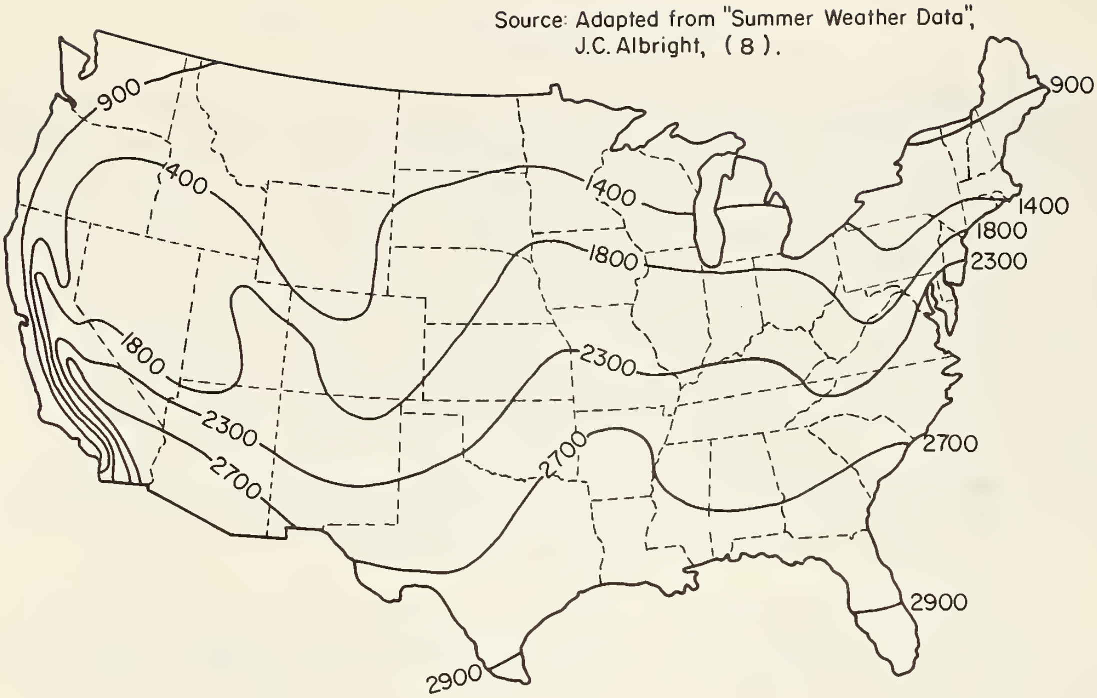


Figure 6. Number of hours normally above conditions of 70°F and 50% relative humidity, June to September, inclusive.

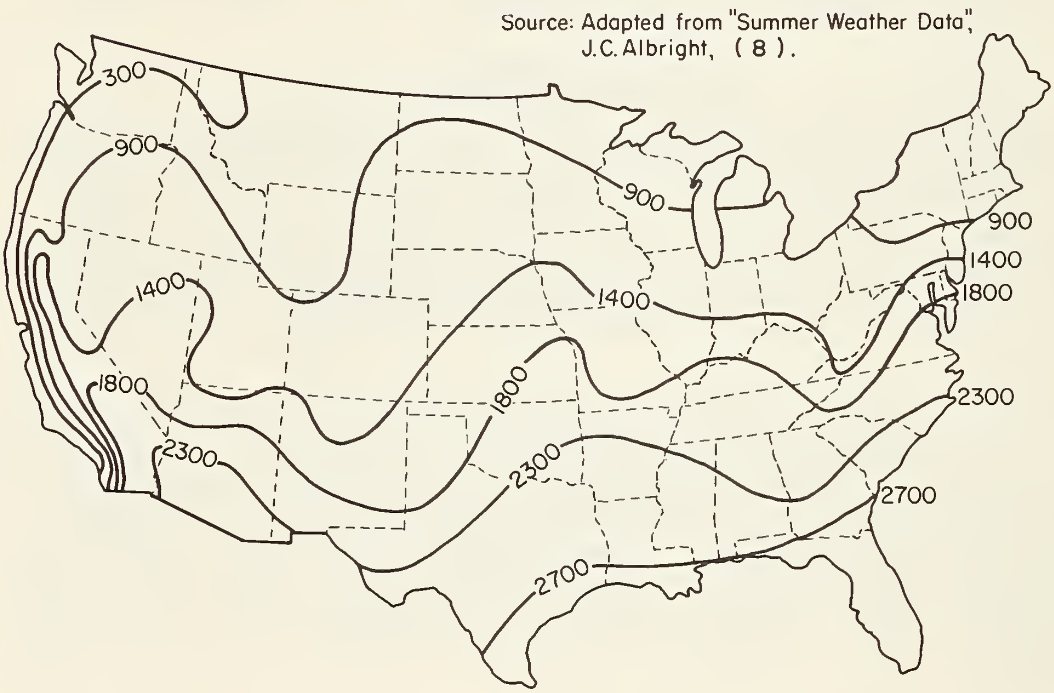


Figure 7. Number of hours normally above conditions of 75°F and 50% relative humidity, June to September, inclusive.

Minimum specifications for hog house air-conditioning refrigeration equipment should be based on the following:

1) The evaporator (cooling) coil must have a capacity adequate to remove heat gains from all sources in the hog house under design conditions and adequate ventilation rates. The evaporator should be designed to condense enough water to maintain reasonably low humidities in the air conditioned space. In actual operation the inside relative humidity should be in the range of 40 - 75%. To obtain this range a design humidity of 50% is recommended. Provision should be made for draining condensate moisture outside the conditioned space.

2) The condensing unit, which includes the compressor, air- or water-cooled condenser, receiver, high-low safety cutout pressure switch, and motor overload switch, must be balanced with the evaporator coil with regard to capacity. Good air circulation is required around the unit, and the heat from the condensing unit must be discharged outside the building.

3) The room thermostats should be adjustable over the range of 50° to 90°F, and operate on 4 or 5°F differential or less.

SUMMARY

Producers in areas where summer conditions have to date discouraged hog production may find air-conditioning a profitable move. For those producers considering air-conditioning part, or all, of their permanent hog housing, methods are shown for estimating the cooling loads to be expected under most conditions. The guides and charts should also be of value to the qualified engineer who finally designs the system for each particular situation.

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